

PB83-115428

Radiofrequency Measurements Workshop
November 3-5, 1980

(U.S.) Office of Radiation Programs
Las Vegas, NV

Jul 82



U.S. Department of Commerce
National Technical Information Service

NTIS

United States
Environmental Protection
Agency

Office of
Radiation Programs
Las Vegas, Nevada 89114

EPA 520/2-82-010
July 1982

PB83-115428

Radiation



Radiofrequency Measurements Workshop

Workshop Summary

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

BIBLIOGRAPHIC INFORMATION

PB83-115428

Radiofrequency Measurements Workshop, November 3-5, 1980.

Jul 82

Richard A. Tell.

PERFORMER: Office of Radiation Programs, Las Vegas, NV.
EPA-520/2-82-010

Experiences with the use, application, design, and limitations of currently available instrumentation for assessing potentially hazardous electromagnetic fields are discussed. Field and laboratory tests were conducted in order to compare differing instruments and measurement techniques under identical field and test conditions. Emphasis was placed on broadband survey types of instruments as opposed to more sophisticated, narrowband measuring equipment.

KEYWORDS: *Meetings, *Electromagnetic radiation, *Radiation hazards.

Available from the National Technical Information Service,
Springfield, Va. 22161

PRICE CODE: PC A02/MF A01

Radiofrequency Measurements Workshop

Workshop Summary

November 3-5, 1980

Workshop Coordinator
Richard A. Tell

Workshop hosted by

U.S. Environmental Protection Agency
Office of Radiation Programs
P.O. Box 18416
Las Vegas, NV 89114

I. Introduction.

As society has increased its dependence upon the use of electromagnetic radiation, its concern about the safety of being exposed to high levels has also increased. The establishment of exposure limits requires the ability to measure these levels accurately and with confidence.

Under the aegis of the Environmental Protection Agency, Nonionizing Radiation Surveillance Branch, a Radiofrequency Measurements Workshop was held at its facility in Las Vegas, Nevada, during November 3-5, 1980. Thirty three individuals (Appendix A) from twelve U.S. Government agencies, one State agency, one Canadian agency and four private companies discussed their experiences with the use, application, design, and limitations of currently available instrumentation for assessing potentially hazardous electromagnetic fields, and participated in field and laboratory tests in order to compare differing instruments and measurement techniques under identical field and test conditions. Emphasis was placed on broadband survey types of instruments as opposed to more sophisticated, narrowband measuring equipment.

were discussed.

were conducted

II. Agenda.

The workshop consisted of a combination of group discussions and field and laboratory work. The discussions were held on November 3 and 5, the laboratory tests and instrumentation demonstrations occurred the evening of November 3, and field measurements were accomplished on November 4.

A. Informal Presentations

As impetus for discussion, nine informal presentations were made by various workshop attendees. These are summarized as follows:

1) Dr. David L. Conover, NIOSH, presented extensive data on comparative performance evaluations of several electromagnetic radiation survey instruments including the General Microwave (General Microwave Corporation, Farmingdale, NY) Raham Model 2, the Narda (The Narda Microwave Corporation, Hauppauge, NY) Models 8635 and 8644, and the Instruments for Industry (Instruments for Industry, Incorporated, Farmingdale, NY) Model EFS-1. Test results were given for instrument field amplitude linearity, isotropicity, absolute calibration, and frequency response. Dr. Conover said that he would like to see individual polarization readout in survey instruments and field amplitude readouts calibrated in units corresponding to the parameter of the field measured, e.g., instruments responding to E^2 should be calibrated in terms of E^2 , not plane wave equivalent power density.

2) Mr. Bob Curtis, OSHA, described industrial situations where OSHA has found very high radiofrequency exposure fields especially near RF sealers and broadcast towers. OSHA has assigned first priority to RF heat sealers and second priority to broadcast towers. His experience has shown that around heat sealers, the equivalent power densities based on electric field strengths are greater than the equivalent power densities based on magnetic field strengths; OSHA has already cited certain facilities at equivalent power density levels in excess of 60 mW/cm^2 . He uses a 30 percent margin for citing purposes due to what he feels is the reliability of his instruments; i.e., the measured exposure levels, in terms of equivalent power density must exceed the OSHA guide of 10 mW/cm^2 by 30 percent. Mr.

Curtis stated that proper shielding could greatly reduce the fields around the RF sealers especially during the manufacturing of small items. Relative to exposure to broadcast radiation, OSHA is working with the FCC to develop a means by which tower and antenna maintenance workers would not be overly exposed. To date, no broadcasters have been cited by OSHA for exceeding their guide. He prefers the concept of equivalent power density for ease of communication with industry. Mr. Curtis also pointed out that some of the instrumentation problems observed by other workshop participants were not apparent in some of his measurements, most notably on RF heat sealers, even though he used the same model instruments, because of the rapid spatial decay of the fields around these devices. OSHA issues citations on the basis of equivalent power density for microwave frequencies, and either electric or magnetic field strengths for frequencies less than 400 MHz.

3) Mr. Howard Bassen, BRH, described techniques used by BRH to evaluate microwave oven survey instruments and radiofrequency survey instruments used primarily in the 27 MHz ISM band. These performance evaluation techniques are described in detail in BRH publication (FDA) 80-8122 for microwave oven instruments and in a future BRH publication for the lower frequency devices. In practice, he finds that microwave oven survey instruments are accurate to ± 2 dB. Preliminary evaluations of instruments at 27 MHz have shown worst case errors of 3-6 dB. Mr. Bassen emphasized his concern that isotropic instruments should be evaluated for isotropicity by rotating the entire probe in such a way that the handle is oriented parallel to the electric field.

4) Mr. Paul Ruggera, BRH, described his experience in measuring lower frequency electromagnetic fields using both survey instruments and small calibrated active antennas with spectrum analyzers. Active antennas employ electronic circuits for compensation, impedance matching, and preamplification of received signals. Mr. Ruggera presented information on several development projects done for and by BRH to develop new instruments including a one-of-a-kind orthogonal loop sensor system developed by Southwest Research Institute (San Antonio, TX) and a special three-axis EFS-1 known as the RHM-2 (Instruments for Industry). Although both the EFS-1 and RHM-2 were described as quite accurate instruments, they are not well suited for some types of

field surveys, such as climbing broadcast towers, because of their physical configuration which requires interchanging antennas to obtain their full dynamic range. Mr. Ruggera pointed out the usefulness of small active antennas (approximately 30 cm in length) that can be used with spectrum analyzers and field intensity meters for spatial resolution of complex electromagnetic fields. In his experience with a SAS1/A antenna (Antenna Research Associates, Beltsville, MD) which consists of a top-loaded monopole for lower frequencies and a discone for higher frequencies with associated electronic networks for impedance matching, i.e., an active antenna, he had found that the manufacturer's stated antenna factor was about 10 dB too low over the 10 kHz to 100 MHz range. He found the active dipole-type antenna, the ADA/10A, by the same manufacturer, to have the correct manufacturer-supplied antenna factor over this range. In his opinion, passive antennas tended to be more accurate than active ones. In his work with the General Microwave Model 2 broadband meter, he found inconsistencies among the three meters he tested.

5) Mr. Jim Miller, USAF, described the approach used by the Air Force for accurate measurements of the emissions from pulsed emitters, in particular the PAVE PAWS radar on Cape Cod, MA, but also for measurements of fixed, scanning, and height finder radars. In the PAVE PAWS measurements it was important to measure both the peak and time-averaged field amplitudes, making use of both narrowband tuned receivers and antennas and power meters in conjunction with computer control. He commented that field measurements of the type he described could probably be performed with 14 dB uncertainty using tuned antennas and receivers. Mr. Miller pointed out that in many instances broadband, portable survey instrumentation is not sufficient for evaluating electromagnetic field intensities, especially when it is important to separate signals in the frequency domain. Being uncertain about the capability of the broadband instruments in a moving beam and requiring that average power levels as low as a nanowatt be measured, he selected a Hewlett-Packard 436A power meter, 8484A power sensor and a 9825A desk top computer which during laboratory tests with PAVE PAWS signal replication was found to have 12 dB accuracy. In fact, it was his experience that near the PAVE PAWS antenna, 3 Narda broadband meters indicated fields that were 3 times greater than

indicated by his instrumentation. The reason for the variation was not explained.

6) Mr. Bill McEnroe, Dupont Haskell Laboratories, presented data he had collected during his previous employment with the U.S. Coast Guard pertaining to Loran C (100 kHz) and Omega (10 kHz) navigational systems. He measured electric and magnetic field strengths around these systems with several prototype instruments of unknown specifications developed by Delta Electronics (Springfield, VA) and an oscilloscope connected to dipole and loop probes. The Delta Electronics instruments were calibrated for 10-15 kHz with the electric field meter providing a readout of 1-35 kV/m and the magnetic field meter providing a readout of .01-5 A/m. For electric fields below 1 kV/m, Instruments for Industry equipment were utilized.

7) Mr. Ezra Larsen, NBS, reviewed NBS methods for establishing calibration fields which employ TEM cells, waveguides and standard gain horns. He also discussed the NBS development of the EFM-5, a broadband electric field meter covering the frequency range of 100 kHz to 1 GHz. Mr. Frank Ries, NBS, said that NBS is attempting to develop a pocket dosimeter for the Navy under a five year program. The dosimeter would provide a complete exposure history in terms of levels and amounts of exposure, and not merely an integrated dose. In this regard, the dosimeter, as envisaged, would at least record the frequency in three frequency bands, 2-30 MHz, 30-300 MHz and 300 MHz-23 GHz; both the total electric and total magnetic fields up to 300 MHz; and the x, y and z components of the fields. The instrument will record from 6 to 334 volts per meter in 6 bands. Mr. Ries estimated that NBS would be able to achieve a 10 dB uncertainty in the overall dose.

8) Mr. Dwight Heasty, RCA Service Company, discussed the problem of making shipboard electromagnetic field measurements of radiation produced by scanning beam radars. He described his development of an auxiliary device which averages the meter reading from the recorder output jack of a Narda microwave monitor. The device essentially provides the average value of the indicated power density and assists the operator when there are rapid swings of the meter due to intermittent illumination of the Narda probe by rotating or scanning radar beams or other radio equipment.

9) Mr. Howard Bassen, BRH, made a final presentation during which he pointed out the latest draft of a "Recommended Practice for the Measurement of Hazardous Electromagnetic Fields - RF and Microwave" developed by the ANSI C95.3 subcommittee dated April, 1980. Copies of this document will be sent to each workshop participant by Mr. Tell. Mr. Bassen then discussed the BRH development of a new electric and magnetic field probe which includes both orthogonal dipoles and loops for sensing of both E and H fields. At the present time, the field sensor is capable of covering the 10-100 MHz region. The unit is a prototype.

B. Field/Lab Activities

In order to evaluate the performance of different instruments and measurement techniques under similar electromagnetic environments, one day was devoted to field activities. These specific field activities included (1) measurements at Nellis Air Force Base near a GPN-22 precision approach radar and near a fire control radar used in a F4 aircraft; (2) measurements at AM standard broadcast radio station KDWN, a 50 kW station using a single vertical monopole antenna; and (3) measurements at Nevada Bell in Las Vegas. In addition, at Nevada Bell, several demonstrations using EPA equipment were set up including a spectrum analyzer with a dish antenna to measure the microwave emissions from a Nevada Bell antenna, a conical-log spiral antenna connected to a power meter to measure the same microwave emissions, a spectrum analyzer connected to the NBS developed orthogonal, resistively loaded antenna for measuring fields in the FM radio broadcast band, and the EPA radar measurements system that utilized a computer controlled spectrum analyzer to observe the antenna rotational duty cycle of an ASR-7 radar at the local airport.

In addition to the discussion sessions and field activities, time was allocated for brief instrument evaluations in the EPA laboratory where two TEM cells were available for establishing accurately known electromagnetic field intensities. Workshop participants were also given the opportunity to see the FCC TV enforcement truck brought by Dane Erickson and the EPA measurement van.

C. Observations on Selected Instruments

The observations reported here are derived from the discussions and field/lab activities. They are not necessarily complete and are in some instances based on limited data.

1) Holaday 3001 - Although this instrument is new and has received limited use, those who had used it reported very favorable experiences. The Holaday instrument uses diode detectors in the probe. It provided accurate (10.5 dB) response when tested at 300 MHz and within the 1-150 MHz range. Holaday Industries provides quick and personal response to inquiries regarding problems. The 3001 has a good feature for field work, an automatic zero circuit which eliminates the need to shield the probe in order to check the instrument zero-set. It is also good for broadcast measurement work.

2) IFI EFS-1, RHM-2 - These instruments, manufactured by Instruments for Industry, were not used during the workshop but were reported on during the presentations. The IFI instruments employ diode detectors with a field effect transistor between the detector and the probe itself. The probe is a monopole rod, a few inches in length, extending from the electronics box. The instrument, for survey purposes, must be held on the end of a dielectric handle to avoid touching the instrument with the body and thereby changing its field strength calibration. They appear to be accurate and reliable when used in their intended frequency range (10 kHz - 200 MHz). The RHM-2 is a three axis device similar to the EFS-1. It appears very useful for RF heat sealers but has the limitation of reading 300 V/m maximum field strength for the standard unit, and up to 1000 V/m when used in conjunction with special antenna stubs. The instruments are cumbersome in that the small sensing antennas must be changed to achieve their full dynamic range, which is unacceptable from the standpoint of certain field surveys, such as those requiring the climbing of broadcast towers. Dave Conover found the EFS-2 to be very sensitive to 60 Hz and harmonic fields generated by fluorescent tubes and power cords. He was able to observe full scale deflections when the instrument was only 2-3 inches from these devices.

3) General Microwave Raham Model 2 and Model 4 - The Model 2 is a two axis instrument whereas the Model 4 is supposed to be isotropic. Both devices use diodes as the field detectors. Chuck Hicks indicated that the Army had good experience with the Model 2 in the microwave range; they determine the calibration both before and after use in the field. Dave Conover reported a Model 2 reading between 3 and 10 dB low and Paul Ruggera found the Model 2 to read 6 dB low when used near a 27 MHz heat sealer. Two Model 4 instruments were available during the workshop. Both of these units read approximately 3 mW/cm^2 when exposed to a 10 mW/cm^2 field at 300 MHz. When used at lower frequencies the units displayed a varying response, generally increasing with decreasing frequency until they read 120 mW/cm^2 at 10 MHz when subjected to 1 mW/cm^2 fields and even higher at lower out-of-band frequencies. When used in the field, the Model 4 appeared to be sensitive to sunlight; this light sensitivity was confirmed later at the lab by shining a high powered flashlight on the probe and observing an increase in response. In a comparison measurement with the Narda instrument, the Model 4 read 10 dB higher at a distance of 30 meters from the GPN-22 transmitting antenna; near its surface, both instruments read the same value. When used at a location off to one side of the GPN-22 antenna, the Model 4 read an off-scale value for no apparent reason even out to a large distance, a position which was clearly out of the beam.

4) Narda (various models) - Since Narda markets a broad line of survey instruments, many of the participants have had experience in using one or more of the models. All Narda instruments, regardless of model number, employ thin-film thermocouples as the detection element. The Narda H field probes have a common and serious problem; they often read negative in strong fields. One participant claimed a lack of success in using the Narda H field probe under field conditions and another commented that he had stopped using his because the incidence of negative readings left him with a lack of confidence. These participants felt that it may be an EMI or pickup problem. During the field exercise, several of the Narda 10-300 MHz H field probes were observed to read negative when used near the 720 kHz AM radio station, signifying a possible problem with the out-of-band response. This same response characteristic was found by BRH for 3 of the 4 Narda H field probes exposed to high fields during a laboratory evaluation. In fact, during this

laboratory evaluation, the responses of the probes varied sufficiently to suggest a problem in quality control. Douglas Hill's experience with the H field probes corroborated this. He found the same model instruments giving readings that varied by a factor of up to 2-3 times. He also made other observations about the Narda H field monitors that included:

- a) a ten to fifteen minute meter warmup time is needed,
- b) the meter zero drift over a fixed period of time is greater if the probe is exposed to radiation during that time,
- c) the error in the readings (7 percent) as the probe is rotated about its handle is negligible in comparison to the day-to-day reproducibility (factor of 2 on the lower end of the lowest scale). Over a few hours time, the meter readings are reproducible within 20 percent,
- d) when hand-held, both the meter and probe must be held in order to avoid the possibility of erroneous readings. Even then, the operator can act as an antenna or a reflector so as to introduce further complications, and
- e) the probe appears to respond to the electric as well as the intended magnetic field.

The Narda Model 8644 E field probe designed for 10-3000 MHz operation for fields up to 2000 mW/cm^2 did not exhibit the negative readings in a high 720 kHz field, as did the H field probes, but was reported by a workshop participant to over respond to E fields at 27 MHz; also, at 27 MHz, a 6 dB variation in response was realized by rotating the handle. Douglas Hill reported that the models 8315A and 8316B, designed for the microwave region, had RF pickup problems indicating that while the meters were useful for work close to the source, care needs to be exercised in using these models in the general environment. Several participants indicated excessive drift problems on the lowest range with both E and H field model Narda instruments. It was noted that only six of the high level E field probes (8644) and six of the high level H field probes (8635) were known to be in existence. OSHA reported

a generally favorable experience with the 8644, 8635 and 8633 probes. Tests in a TEM cell indicated errors of less than 10 percent for the frequency range tested (10-150 MHz). BRH reported that at 2450 MHz, a model 8300 was found to be 1 dB low and that 30 units of the model 8100, the microwave oven instrument, averaged only 2 percent low, with the individual response varying from 8 percent above mean to 10 percent below mean. The model 8100 probes were found to drift about 2-3 percent per year and to break down after about 5 years.

D. Observations on Measurement Techniques

Several observations were noted relevant to measurement techniques. It was found that in the near proximity to an AM standard radio broadcast station, all of the survey instruments produced different responses raising the question of whether any of the meters were correct. This included the Holaday, General Microwave and Narda instruments, as well as the NBS EFM-5. The nature of the response varied according to the instrument, but, in general, seemed to indicate a sensitivity to some form of capacitive coupling with the low frequency field such that the instruments became responsive to the radiofrequency space potential between the probe and the electronics readout. In some cases, this was reflected by instrument readings which increased with probe height above ground, as with the Holaday and General Microwave units, while the Narda instrument reading went negative.

When using conventional 41-inch rod antennas in conjunction with an Electrometrics (Amsterdam, NY) field strength receiver, Model EMC-25, to sense the output from these rods, the rods tended to average the field over their length and when used near ground level provided values of E field strength that were typical of those at a midpoint height of the antenna even though there was some variation in the field strength as a function of height above ground. The phenomenon of E field variation with height was not observed when using the Potomac (Silver Spring, MD) FIM-21 field strength meter because it is sensitive to the magnetic field which does not vary near ground level. The Potomac FIM-21 is a tuned receiver, covering the frequency range 0.535-1.605 MHz, which uses a loop antenna contained in the case of the instrument for sensing the magnetic field. It was found that the

Electrometrics field strength receiver, itself, was susceptible to pickup and needed to be kept out of high fields. The Electrometrics receiver covers the frequency range of 14 kHz to 1 GHz and uses external antennas.

The problem of a scanning beam, such as produced by a rotating radar antenna, is not easily solved, from a survey point of view, unless the antenna is stopped so that accurate stationary beam measurements can be made and time averages calculated.

It is important, when measuring high field strengths, to have equipment which is battery powered. This can become particularly important when working around high-powered AM radio stations where sizeable RF currents can be induced to flow in long extension cords used to provide AC power to measurement equipment.

Some participants pointed out the desirability of using a consistent probe orientation with respect to the incident field for consistency in measurement results. Narda, for one, makes such suggestions in its manuals.

In performing field survey measurements it is helpful to keep personnel away from the area being surveyed in order to minimize reflections and/or distortions of the fields. Bob Curtis indicated that this did not seem to be a critical problem with RF heat sealers.

Several participants felt that there was a need for small orthogonal antennas for use with spectrum analyzers and field strength meters for spatial resolution of RF fields in certain locations. At the present time there is no commercial source for such antennas.

There appeared to be a concern by various individuals as to the need for measuring both E and H fields, the frequency ranges over which this is necessary, and the additional complications introduced by such measurements.

E. Other Problems/Observations

1) Meter Output Units - Some instruments are not calibrated in terms of the field parameter which they directly measure. For example, Narda and General Microwave instruments are calibrated to read in units of equivalent power density even though they are actually responding to the square of the electric or magnetic field. The Potomac FIM-21, a standard in the broadcast industry, is calibrated in terms of electric field strength while it actually responds to the magnetic field. Many antennas are also supplied with conversion factors to yield electric field readings instead of magnetic fields which they sense. Many individuals preferred to have instruments which report the actual field parameter which it senses.

2) Units - It was clear that it was desirable to have instruments which measure the appropriate parameters of the field as stated in standards. It was also concluded that the introduction of frequency dependent standards would put a significant strain on instrumentation and measurement techniques.

3) Achievable Accuracy - This area was discussed at length. Several participants said that a range of 2-4 dB was possible, 2 dB being associated with microwave ovens and 4 dB being associated with more difficult field measurements.

4) Narrowband vs. Broadband Measurements - Frequency dependent standards will require narrowband information. Narrowband instruments are routinely used in present measurements to better define the problem and help determine the appropriate survey equipment to use for subsequent measurements.

5) Training - Surveys are now being conducted by presumably knowledgeable personnel, yet it has become apparent that in some cases mistakes are being made. This is due to the specialized nature of RF hazard measurements and to the pitfalls often associated with these measurements and reflects a need for the training of personnel having responsibility for such measurement tasks.

6) Out-of-Band Response - General radiofrequency hazard meters are frequently used in environmental surveys where the situation is not well controlled. Fields from unwanted sources combined with poor out-of-band instrument responses can produce highly erroneous results to the unaware user.

7) Calibration Facility - The participants agreed that there is a substantial need for a facility that could economically provide reliable calibration services and checks for their instruments over their entire ranges. This seemed to be important because there is a general tendency to lack confidence in instruments performance over long periods of time and when they are subjected to different kinds of electromagnetic environments and/or other physical and chemical insults.

III. Conclusions.

At present, the state of the art of electromagnetic survey instrumentation and survey techniques is such that under certain conditions, valid measurements can be made; however, a general statement about the validity and reliability of such measurements under all conditions cannot be made because of the following problems:

1) Published instrument specifications are generally incomplete; e.g., it is often unclear as to the applicability of frequency response data at frequencies where the instrument was not calibrated and there is usually no indication as to out-of-band performance or susceptibility to interference from radiofrequency signals (RFI) by the instruments.

2) Published instrument specifications are often unreliable; e.g., the response of individual instruments does not always agree with the calibrations provided by the manufacturer.

3) Measurements are often made under uncontrolled and/or unknown conditions.

4) Measurements are often made with instrumentation and/or techniques inappropriate to the conditions present at the time and location of the measurement.

5) In general, there is a lack of suitably calibrated antennas, for various regions of the spectrum, that can be used for spatial characterization of the electromagnetic environment in a given frequency domain.

IV. Recommendations.

Based on the conclusions reached at the workshop, two basic recommendations were formulated:

1) For broadband radiofrequency survey instruments, the workshop participants recommended that a group such as ANSI

- a) set a standard for minimal uniform reporting of performance characteristics for existing instrumentation;
- b) set a standard for minimal testing procedures for evaluating instrument performance;
- c) set a standard for performance characteristics for future instruments.

2) Standardized measurement techniques be developed based on existing instrumentation, applicable standards, and exposure situations.